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Sources of Acoustic Emission in Aluminum Alloys

Abstract

I'd like to start the talk with a brief description of this task on acoustic emission (AE) source identification in terms of its immediate aims and ultimate goals. The _immediate aims were to, first, identify the sources of AE in a variety of materials, making a survey of just where they originate, and their dependence on changes in microstructure. The second aim was to identify characteristics of the AE signals which might be related to these sources and, therefore, indirectly to the microstructural effects. These aims were realized for the materials studied. The ultimate goals of such a study would be the extrapolation of AE data from one test situation or from one material to another, and, ideally, to relate the emissions to a determination of flaw criticality.

Disciplines

Materials Science and Engineering | Structures and Materials

SOURCES OF ACOUSTIC EMISSION IN ALUMINUM ALLOYS*

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I'd like to start the talk with a brief description of this task on acoustic emission (AE) source identification in terms of its immediate aims and ultimate goals. The immediate aims were to, first, identify the sources of AE in a variety of materials, making a survey of just where they originate, and their dependence on changes in microstructure. The second aim was to identify characteristics of the AE signals which might be related to these sources and, therefore, indirectly to the microstructural effects. These aims were realized for the materials studied. The ultimate goals of such a study would be the extrapolation of AE data from one test situation or from one material to another, and, ideally, to relate the emissions to a determination of flaw criticality.

The experimental parameters that were used in this study are listed in Table I along with parameters which would be of interest in future work. These were all intended to either change the microstructure, and thus the deformation and fracture behavior, or change the fracture behavior directly. All these parameters had an effect except for the strain rate which was observed to have no effect on either the AE or the fracture behavior in the range studied.

The alloys that we started looking at were 2024 and 2219 aluminums, and the two steels, A533 and HY80. Very soon into the study we concentrated on the aluminum alloys and expanded the range to include 2048 (which is of similar composition to 2024 except lacking the unintentional impurities), 7075, 6061, and 1100. These are the aluminum alloys that I'll be spending most of the time on, although I will refer to some of the results for the steels where they're significant.

Concerning the experimental observations that we made, first, the event count is somewhat different than the usual ring-down method of counting. In event counting each AE event or burst is registered as one count, whereas in ring-down counting each zero crossing in a rather complex but approximately sinusoidally damped electrical signal is registered as one count.

Strip chart recordings were made during each test of the event count, the event count rate, the RMS voltage of the AE signal and the load. Also, the AE signals were recorded on a broad-band video tape recorder which was modified for analog signal recording. This recording had a bandwidth of up to about 3 MHz, and it had the unique capability of being able to play back any 17 millisecond time increment (or portion thereof) of the recorded signal repetitively. That made frequency analysis of a selected portion of the recorded signal quite easy using a standard swept frequency spectrum analyzer.

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Table I. Parameters of this study on acoustic emission source identification and parameters planned for use in a continuation of this study.

Experimental Variables

Alloy content	
Impurity content	
Heat treatment	
Surface condition	
Specimen orientation	
Specimen origin	
Strain rate	

Specimen geometry	Future
Grain size	
Temperature	

Observations

Event count	}	vs. time
Event count rate		
rms voltage		
Load		
Signal appearance		
Frequency analysis		
Fractography - SEM and optical		

Amplitude distribution	}	Future
Signal phase		

We played back these recorded signals and made general observations about the signal appearance, relative amplitudes, duration, rise time, and modulation on the envelope. We did the frequency analysis of individual AE events and recorded observations of different frequency spectra which occurred at different times during a test. We also did the fractography of the specimens, looking at both the lateral surfaces of the tensile specimens and the fracture surfaces, to determine features in the microstructure which might be related to the sources of the AE events.

Now, the experiment went this way. We took a batch of 10 or 20 specimens, tested them (these were all tensile specimens of identical geometry) and recorded the AE data. Then my co-worker, Dr. Fred Morris, would spend many long hours at the microscope looking for characteristic features on the lateral surface and the fracture surface to try to say something about the crack initiation and how the specimen deformed and finally fractured, counting the occurrence of specific features of these specimens. We then analyzed the AE data and compared these results with the fractography results.

Then, usually Fred would say, "Well, I believe if we changed this parameter, or if we looked at this material, we'll change something in the fracture behavior which may be significant in the acoustic emission behavior also."

So, we prepared another batch of 10 or 20 specimens including some control specimens of identical parameters to the previous batch, tested those, and, sure enough, more often than not Fred was right. But we would always have a few surprises, too, that led us on to another batch of specimens. So, it was an iterative process of learning what to look for and what to correlate with.

Now, I'd like to take Dave Kaelble's stance and present the conclusions from this study early in the game to make sure that I have time.

The conclusions are of two basic types: an identification of the sources of the AE in the alloys, and the characteristics of the AE which can be related to these sources. Since not much had been done in spectral analysis of AE events and we had the capability, that feature was stressed, although we looked at several other features of the AE signals also. Today, I'm going to emphasize the spectral analysis characteristics. What we found was that the primary source of the burst-type AE in all of these alloys was the brittle fracture of 2 to 20 micron diameter intermetallic particles. In some of the materials under some of the conditions, a secondary source was brittle fracture of small regions of the matrix material.

These two sources made up about 99 percent of the sources of all the AE. The relative importance of these sources would change, and the absolute numbers of the sources would change over orders of magnitude with changes in the test parameters. By carefully counting the occurrence of these features on the fracture surfaces, and correlating that with the number of AE events, we could get agreement within a factor of 2 or 3, and I consider that a pretty good indication that we were properly identifying the sources of AE.

There were four distinct frequency spectral types identified in this study (shown later in Fig. 1). About 99 percent of all the AE had either a "white noise" frequency spectrum over a 2 MHz frequency range, or what I call Type II, which is a frequency spectrum which is skewed to higher frequency than "white noise".

Based on some mathematical modeling that you'll hear a little bit more about later on this afternoon by Dr. Bill Pardee, we think we understand the relationship between the observation of these spectral types and the primary and secondary AE sources. That is, the source must be very localized, having a stress release which occurs over a time duration which is short compared to the reciprocal of the highest frequencies that you see in the frequency spectrum of the stress wave.

All right. Those were the bulk of the AE. Now, the other 1 percent or so did not have either of these two spectral types, but were either a Type I which had only low frequency components compared to the white noise spectrum and a Type III which had a peaked frequency spectrum at about 600 KHz. An interesting feature of this is that 600 KHz is the frequency of the radial resonance of the AE transducer. Why these particular AE excite only that resonance of the transducer while all the rest of them tend to excite all its resonances, is not clear at this time.

We can associate the Type III and the Type I with specific features of the fractography. For example, when we saw large areas of either grain boundary separation or flat matrix tearing (as opposed to ductile or cleavage fracture), in those specimens and under those conditions we saw the Type I AE bursts occurring at about the time in the loading history where we could infer that these events took place. In one specimen, delaminations occurred in the matrix material. This was only for one orientation of the tensile axis with respect to the rolling direction of the plate material where that occurred, and again, many Type I AE bursts appeared in that one specimen.

Several of the specimens had a few of the Type III bursts, but there were five specimens where that type predominated. Four of these specimens were all of the same heat-treat condition (2219 and 2024 aluminum). They all showed large areas of matrix cleavage on the fracture surface in contrast to the very small regions of matrix cleavage in between the brittle fracture of the particles that appeared on most of the specimens. However, one of the specimens (6061 aluminum) showed none of that feature and yet the Type III AE bursts predominated. That leaves the identification of the source of that type of spectrum in question.

Another type of AE, which is usually of very low amplitude, is termed "continuous emission". This was only observed in a few specimens in certain heat-treat conditions. We believe this is either due to gross plastic deformation or submicron size particle cleavage due to the plastic deformation but haven't been able to isolate its cause. This AE had a white noise spectrum which might be expected for a very small localized source.

Now, I'd like to show some of the data on which these conclusions were based.

The four spectral types just described are shown in Fig. 1. The solid line in each case is the frequency spectrum of a single AE event of one of the four types. Its amplitude is shown on a logarithmic scale relative to the electronic noise level of the transducer preamplifier combination (the straight line at the bottom of each figure). These particular AE signals were 30 db above the electronic noise. The dotted line superimposed on each of these spectra is the response of the AE transducer to acoustic white noise, which was determined by another method.

About 60 percent of all of the AE were "white noise" as shown in Fig. 1a. You can see that they reproduce the white noise response of the transducer quite well. About 40 percent were of the Type II high frequency type. I have matched the amplitude of the white noise response curve at some arbitrary frequency in Fig. 1b, but you can see that there is about a 20 db difference in amplitude at the low frequency end with this normalization, and perhaps a 10 db increase at the high frequency end giving an overall shift of about 30 db toward the high end of the 0-2 MHz frequency range. The type I spectrum in Fig. 1c is skewed considerably to lower frequencies than white noise, and in Fig. 1d is the Type III spectrum which corresponds to the radial resonance of the transducer. Again, about 1 percent of the bursts were of Type I and less than 1 percent were of Type III overall.

I'd like to summarize the results of our observations for one of the experimental parameters to illustrate the different AE behavior produced under different conditions. The parameter is the effect of orientation of the tensile axis of the specimen with respect to the rolling direction of the plate material. A longitudinal specimen (L) has its tensile axis along the rolling direction; short transverse (D) has its tensile axis through the thickness of the plate; the long transverse (T) is the other orthogonal direction.

The numbers shown in Table II are the number of AE events normalized by the total plastic strain in percent. There were two principal differences between the S- and the L- specimens. There were parallel growing cracks and also a lot of brittle matrix fracture in the S- specimens which accounted for the larger number of AE events. The AE in the L-specimens was due almost entirely to the brittle fracture of intermetallic particles accompanied by the very quiet, ductile fracture of the matrix. The T-specimens were intermediate between these extremes. This behavior is illustrated for 2024 in the micrographs of Fig. 2.

The appearance of the oscilloscope trace of the AE signal at the maximum event rate is shown in Fig. 3 for 7075 (a medium emitter) and 6061 (a low emitter).

The last figure shows some of the anomalous fracture behavior. Figure 4c shows a large planar fracture region which was seen all over the fracture surface of the S-orientation A533 steel in which the Type I AE bursts appeared. Figure 4b shows the delamination of the layered structure in the 2048 Al in the T- orientation, and only in that one orientation were the Type I bursts seen. Figure 4 shows the large regions of brittle fracture of the matrix for a certain heat treatment of 2024 and 2219 which we believe are associated with the Type III frequency spectrum.

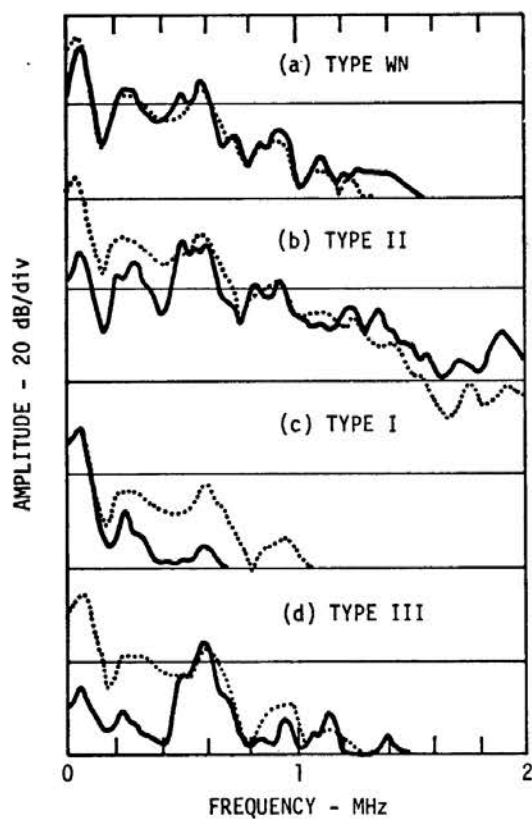


Fig. 1. The four distinct types of frequency spectra which were observed for individual acoustic emission events. The solid curve in each case is the frequency spectrum of an acoustic emission burst referred to amplitude to the straight base line, which represents the flat frequency spectrum of the electronic noise level of the transducer-preamplifier combination. The dotted line is the response of the transducer to acoustic white noise, which is shown for comparison.

Table II. Effect of orientation on N_E/ϵ_p for all the materials tested in the as received condition.

	L	T	S	COMMENTS:
2024 T351	8000	11000	23000	L - Many broken inclusions on fracture surface - ductile matrix fracture. S - More crack growth on parallel planes from crack initiation sites on the lateral surfaces; more brittle fracture of matrix; T-intermediate between appearance of L and S specimens. 90° - (Specimens 1S10 and 1S9) large peak in \dot{N}_E at $\sim \sigma_y/2$.
2219 T851	2800	11000	18000	
7075 T6	2000	-	8000	Insufficient number of broken inclusions on main fracture surface to account for N_E . Sufficient broken inclusions on lateral surfaces - generally ductile fracture.
2048 (T6)	2000	3000	3000	Nearly isotropic fracture and AE behavior - very little brittle fracture of matrix. Delamination in T-orientation. Low inclusion content and fewer broken compared to 2219 & 2024.
6061 T6	400	-	1300	Limited numbers of broken inclusions - increased brittle fracture of matrix in S-orientation contributed to high AE for S.
1100 H14	18	11	-	Very few broken inclusions - very ductile fracture.
A533-B	54	177	1710	Very ductile fracture - few regions of brittle grain cleavage - quite a few large regions of low energy fracture (at grain boundaries?) in S-orientation.
HY-80	24	80	166	Very ductile fracture - few regions of brittle matrix fracture.

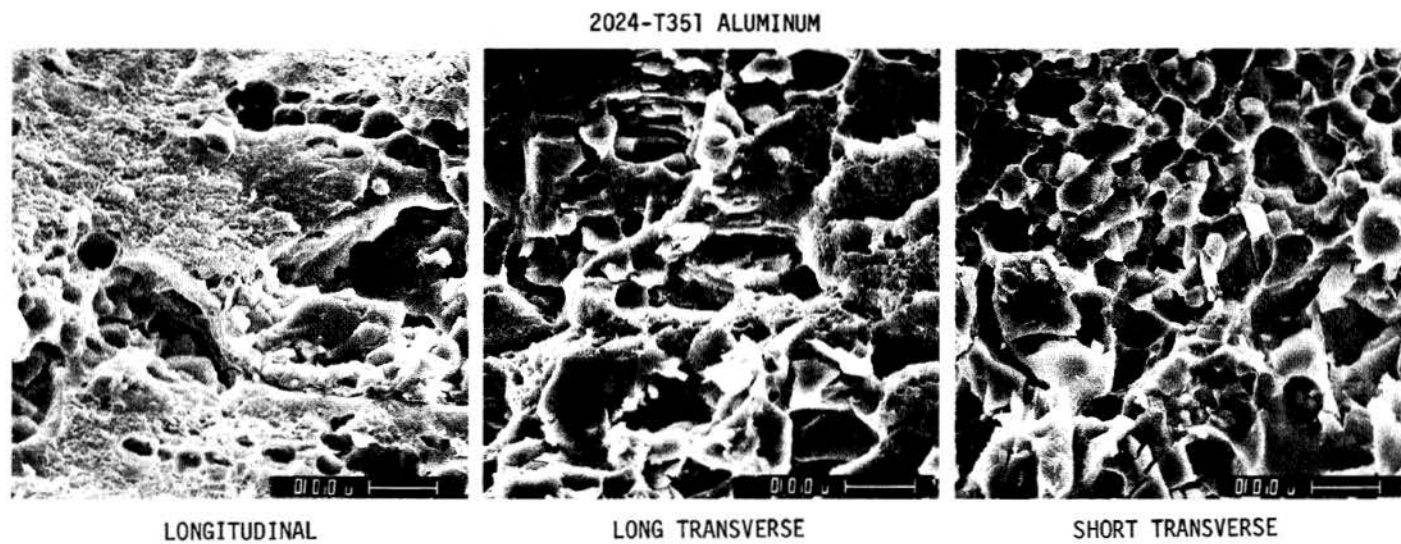


Fig. 2. The effect of specimen orientation on the fracture behavior which was typical of most of the aluminum alloys.

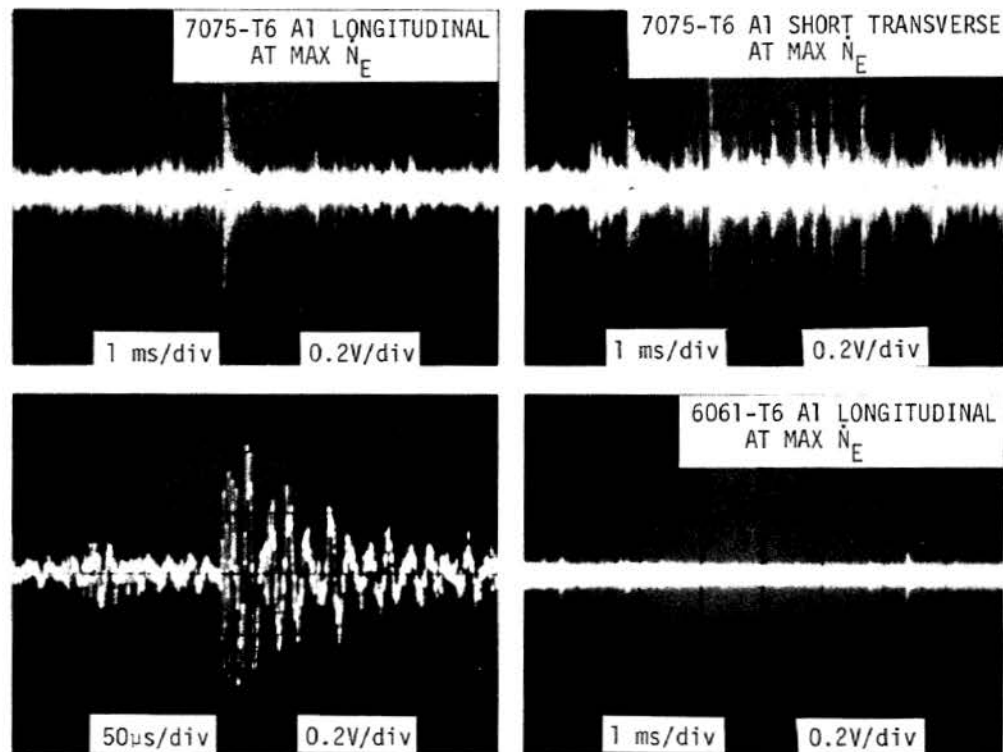


Fig. 3. The appearance of the burst type acoustic emission signals at the maximum event rate in three specimens pulled in tension at a crosshead speed of 0.05 in/min.

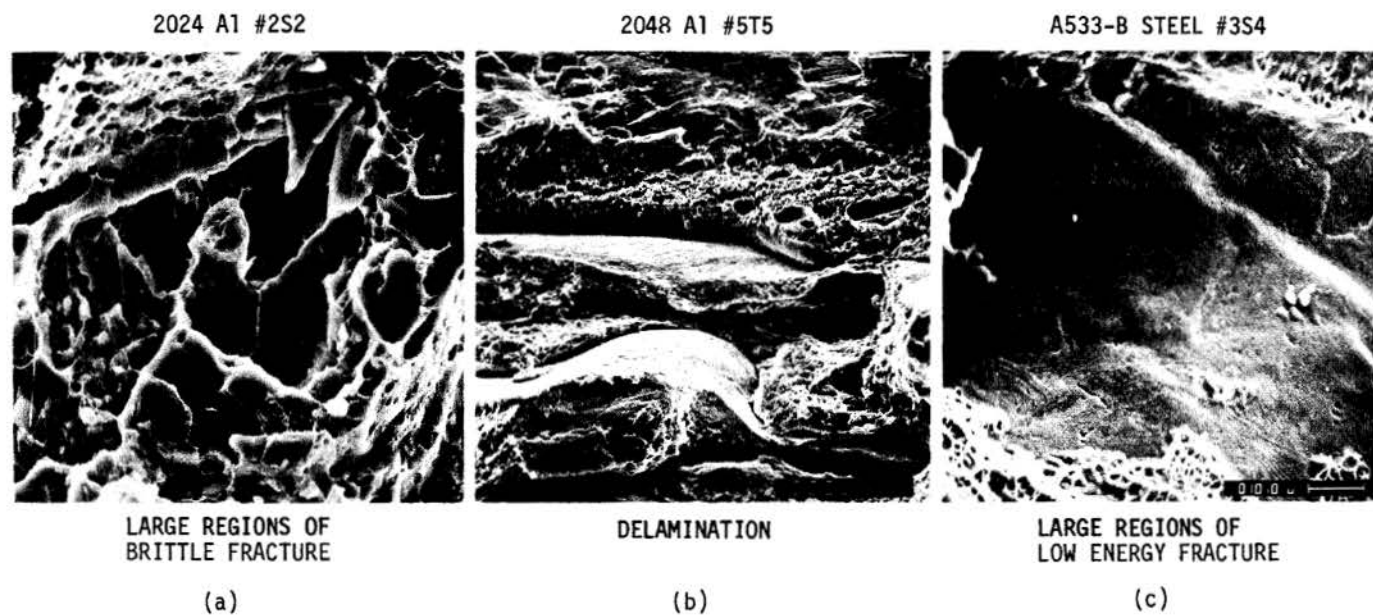


Fig. 4. Regions of exceptional appearance on the fracture surfaces of specimens in which acoustic emissions having the Type I and Type III frequency spectra were observed.

DISCUSSION

DR. TIEN: Thank you Lloyd. I think there's time for a couple of questions.

DR. GREEN (Johns Hopkins University): Could you give us a little bit of detail about your experimental setup, especially with respect to the testing of the frequency response of the video tape recorder, the calibration of the transducer, and the geometry and location of the transducer with regard to the specimen?

MR. GRAHAM: That's a big order. I can take you back to the lab and show you. Briefly, calibration of the frequency response of the video tape recorder was done electrically, putting a swept frequency signal in at different amplitudes and observing the amplitude on playback as a function of frequency. Calibration of the transducer was done by fracturing small silicon carbide particles continuously in a kind of mortar and pestle (fashioned after the device of Bob Chambers at The University of Arizona) to produce an acoustic "white noise" source.

Finally, the geometry of the specimen is shown in Fig. 5. The reduction between the gauge length and the massive v-notch gave us a quiet loading situation.

DR. GREEN: Was it tested in an Instron test machine?

MR. GRAHAM: Yes.

DR. GREEN: Did you make any special efforts or any special technique to eliminate the noise from the machine coming into the acoustic emission transducer?

MR. GRAHAM: Yes.

DR. GREEN: Could you comment on that?

MR. GRAHAM: The frequency range of the 24 dB per octave bandpass filter used was 50 KHz to 3 MHz during recording and that eliminated all the machine noise. Also, the specimen was electrically isolated from the load frame, and as a side effect, somewhat acoustically isolated.

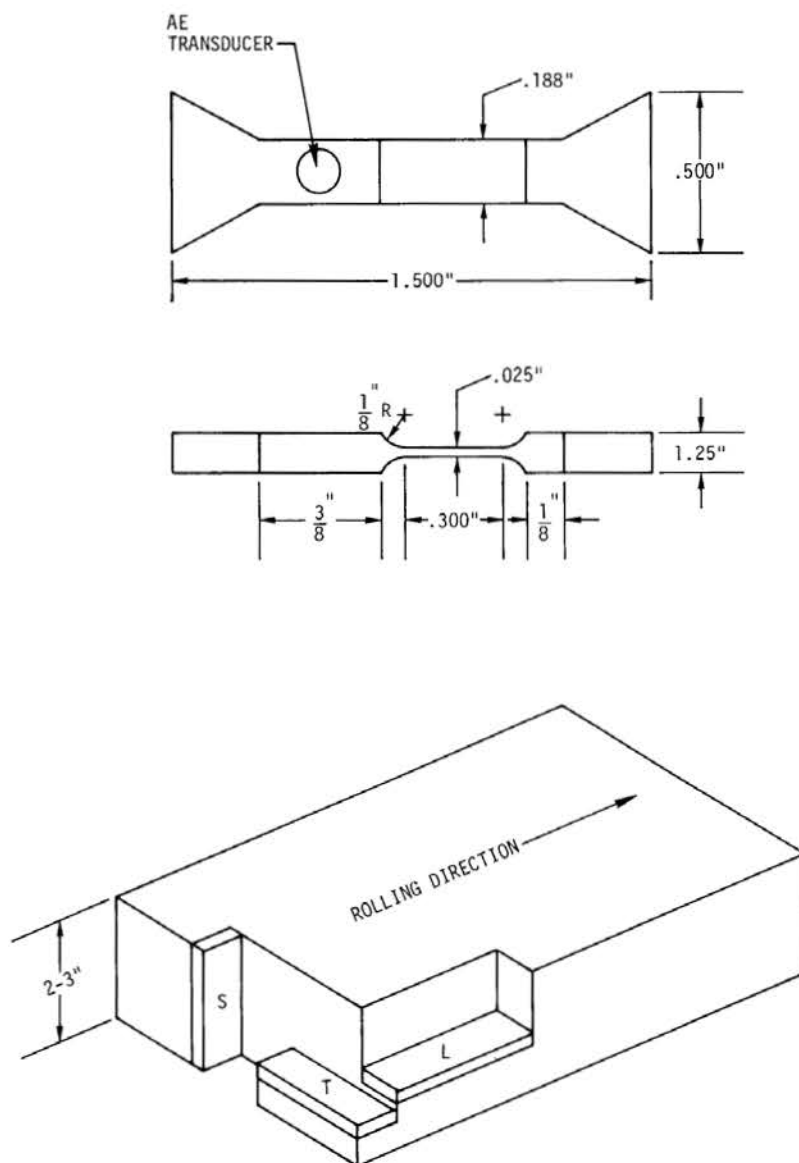


Fig. 5. Tensile specimen configuration which was used throughout the study and the orientation of their tensile axes in the rolled plate material.